REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Feb. 24, 1995	Final 6/1/91-12/31/94

4. TITLE AND SUBTITLE
Clouds--Their Prediction and Simulation

5. FUNDING NUMBERS
61102F 2310A1

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research/NM
110 Duncan Avenue, Suite B115
Bolling AFB, DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFOSR-91-0269

19950403 027

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. Physically-based cloud forecasting algorithms have been developed in support of the long range goal of developing a comprehensive mesoscale numerical prediction cloud forecast system.

Algorithms for forecasting cirrus clouds include development of both heterogeneous and homogeneous ice nucleation schemes, a double-moment ice crystal distribution parameterization, liquid and ice saturation calculations at very cold temperatures, and of radiative properties of cirrus. The impact of these algorithms on mesoscale prediction of cirrus has been evaluated for a number of FIRE I and II cirrus data sets.

One of the FIRE stratus cases was simulated to evaluate various boundary layer cloud fractional coverage schemes. The best performing schemes have been interfaced with the RAMS radiation codes for forecasting boundary layer stratus.

A convective cloud parameterization scheme designed for use in mesoscale models has been tested against data observed during the CaPE over South Florida. Improvements to the cumulus parameterization scheme are now being made and tested.

A new two-moment microphysics scheme has been developed, implemented and tested in RAMS. The additional degrees of freedom in this scheme allow a more realistic prediction of cloud microstructure and corresponding radar reflectivities and optical depths.

14. SUBJECT TERMS
cloud prediction, cirrus, stratocumulus, mesoscale modeling, radiative transfer, cloud physics.

15. NUMBER OF PAGES
12 pages

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

FINAL TECHNICAL REPORT AFOSR-91-0269

AFOSR-TR- 95 - 0222

For Period 1 June 1991 – 31 December 1994

CLOUDS – THEIR PREDICTION AND SIMULATION

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Contents

Abstract

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1 Introduction

This represents a final Technical Report on AFOSR contract #AFOSR-91-0269 for the period 1 June 1991 – 31 December 1994.

The long range goal of this research is to develop a comprehensive mesoscale numerical prediction cloud forecast system that can be used to support U.S. Air Force operations. To meet that goal we are developing and testing physically-based cloud forecasting algorithms that are sufficiently general to be useful in operational theaters anywhere in the world. These physically-based algorithms have been implemented in RAMS an an integrated, interactive package. Moreover, the more successful of these algorithms are being further tested by running them daily in a realtime forecast version of RAMS run on high-performance workstations.

2 Research Accomplishments

2.1 Forecasting Cirrus Clouds

Research in developing the capability of forecasting cirrus clouds includes developing and refining models of heterogeneous and homogeneous nucleation of the microphysics of cirrus

clouds (Meyers et al., 1993; DeMott et al., 1992, 1994), developing a parameterization for transfer of pristine crystal mass and number concentration to snow and vice versa (Harrington, 1994; Harrington et al., 1995), extending methods for determining saturation vapor pressures at the very cold temperatures characteristic of cirrus clouds (Flatau et al., 1992), and developing parameterizations of the radiative properties of cirrus (Flatau et al., 1993; Flatau et al., 1992; Flatau, 1992).

In addition, using RAMS, we have performed exploratory mesoscale simulations of several cirrus case studies observed during FIRE I and II (Heckman and Cotton, 1993; Pielke et al., 1992; Heckman et al., 1991; Heckman, 1991; DeMott et al., 1994) as well as prototype realtime mesoscale forecasts of cirrus (Cotton et al., 1994; Thompson and Cotton, 1992, 1993; Thompson, 1993).

We are now in the process of repeating the FIRE II case study simulations with the new version of the RAMS microphysics.

2.2 Forecasting Boundary Layer Clouds

We have been examining the potential of forecasting boundary layer clouds using the small scale turbulence parameterization developed by Weissbluth and Cotton (1993). We have interfaced this scheme with several cloud fractional coverage schemes and tested their performance against data observed during the 7 July 1987 FIRE marine stratus case (Betts and Boers, 1990) and for a continental boundary cloud case observed during the 1983 Boundary Layer Experiment (Stull and Eloranta, 1984). As described by Mocko and Cotton (1993, 1995) the schemes which performed the best were the simple relative humidity-based schemes of Sundqvist et al. (1989) and Kvamsto (1991) as well as the Ek and Mahrt (1991) scheme. These schemes are being interfaced with the Chen and Cotton (1987) radiation scheme in RAMS.

2.3 Forecasting Transient Cumuli and Cumulonimbi

At this time it is not possible to perform explicit simulations of cumuli and cumulonimbi in a realtime mesoscale forecast model. Even at grid spacings of 5-10 km, some form of

convective parameterization is required. The convective parameterization scheme developed by Weissbluth and Cotton (1993) was designed for small mesoscale grid spacings but it was calibrated for only intense cumulonimbus clouds such as supercell storms and squall line thunderstorms. As a result we have found that it does not perform well, in general, when the prevailing cloud types are transient cumulonimbi and towering cumuli. In some specific cases, the scheme does perform quite well such as one of the Convective and Precipitation Electrification Experiments (CaPE) examined by Edwards (1993).

Scot Randell has therefore taken on the task of extending or developing a scheme that overcomes the deficiencies of the Weissbluth and Cotton scheme. Because the Weissbluth and Cotton scheme is quite time-consuming, it appears that quite a different approach from what they used will be needed.

2.4 Cloud Microphysics Parameterization

The new single-moment microphysical scheme described by Walko et al. (1994) which was implemented into RAMS has been extended to prediction of two-moments of the hydrometeor distributions. This new scheme described by Meyers (1995) allows prediction on both the concentration and mixing ratio of the distribution function for each hydrometeor category making the determination of each hydrometeor size spectra less arbitrary. With more detailed physics the model should have the potential to allow for the evolution of the hydrometeor spectra and provide improved forecasts of radar reflectivity and cloud optical depths. The new microphysics also allows prediction of an additional hydrometeor species, hail. Some highlights of the model include:

- The use of a generalized gamma. size-spectrum where the ν parameter can be prescribed by the user as opposed to a fixed Marshall Palmer spectrum.

- The introduction of ice-liquid mixed phase graupel and hail categories categories with non-thermal equilibrium for the rain, graupel and hail classes.

- New heterogeneous and homogeneous ice nucleation parameterizations.

- Approximate solutions to the stochastic collection equation rather than the continuous accretion model approach.
- Breakup of rain droplets is formulated into the collection efficiency.
- Analytical flux equations predict mixing ratio and number concentration conversion from pristine ice crystals to snow due to deposition (no riming).
- Predictive equations for ice nuclei (IN).
- Crystal habit is diagnosed dependent on temperature and saturation
- Evaporation and melting of each species assumes that the smallest particles completely disappear first.
- More complex shedding formulations which take into account the amount of water mass on the coalesced hydrometeor.

After testing the new scheme, two case studies were examined, a wintertime orographic precipitation event over the Front Range of Colorado from the Winter Icing and Storms Project (WISP91), and a summertime convective case over the High Plains of Montana from the Cooperative Convective Precipitation Experiment (CCOPE81). These cases allowed comparisons between the two-moment predictive scheme and the one-moment predictive scheme and highlighted the advantages of independently predicting on two moments of the hydrometeor spectra. Detailed analysis was also done on these two cases with special attention given to radar reflectivity, aircraft, and ground-based measurements.

2.5 Other Cloud-forecasting Research

Other research conducted during this period includes:

1. quantitative precipitation forecasts of wintertime orographic cloud from the Sierra Nevada range of California (Meyers and Cotton, 1992).
2. simulation of a Front Range Colorado blizzard (Meyers and Cotton, 1993).

3. simulation of a downslope windstorm including investigation of the effects of clouds and precipitation (Beitler et al., 1994; Cotton et al., 1995).

3 Graduate Students Supported

Brian Beitler	M.S. graduate student (AFIT)
Ben Edwards	M.S. graduate student (AFIT)
Piotr J. Flatau	Ph.D. graduate student
Scot Heckman	M.S. graduate student (AFIT)
Jerry Harrington	M.S. graduate student
Michael Meyers	Ph.D. graduate student
David Mocko	M.S. graduate student
Gregory Thompson	M.S. graduate student

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5.2 Conference Papers

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